1: Eppur si Muove (Part II)

Physics 17: Black Holes and Extreme Astrophysics

Zoom

- We will meet for class on Zoom
- If you are able to put your camera on, it would be great to see everyone (just like we would in a physical classroom)!
- Please mute your microphone whenever you are not speaking (there's about 60 of us here – that can make a lot of background noise!!)
- You can talk during class with others using the chat feature in Zoom, but please do so sparingly as this can be distracting
- We will use some interactive features such as polls
- The Zoom classes will be recorded

Breakouts

- During each class, we will have around 2 breakout sessions
- We will divide into groups to discuss ideas and answer a few questions
- We will always work in the same groups for the first half of the quarter
- Each time, nominate one member who will report your answers back to the class (this should be someone different each time)
- Try to let everybody speak
- Instructors and TAs will drop in to listen to your conversations
- We are most interested in the concepts, rather than detailed calculations

Homework

- Weekly homework
  - 4 questions, 8 points total per week
- Final homework
  - 1,000-word term paper on a topic of your choice related to the course
  - 16 points
  - More information to follow
- Submit your answers via Gradescope

Collaboration

- We encourage you to work with others in the class to discuss the course material or homework
- But you should submit your own answers to the homework
- Canvas has text chat for this course
- You can also set up Zoom meetings one-on-one or in groups
- This Zoom meeting is available as a virtual room outside of class times to drop in to

Connect to PollEverywhere

pollev.com/wilkins

Motion in a Circle

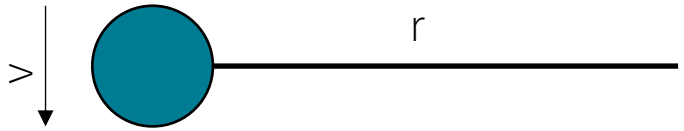
Question

We have a ball spinning on the end of a string, travelling in a circle at a constant speed v.

What is the velocity of the ball? Does it stay constant or does it change?

Is the ball accelerating? If so, what direction is the acceleration?

What is causing the ball to accelerate?



Motion in a Circle

- The speed of the ball is constant, but it's velocity changes (velocity has a direction) so it stays tangent to the circle
- Therefore, the ball accelerates, caused by the force of tension in the string:

$$\Delta v = a\Delta t$$

- Think about how the ball moves in a very short time, Δt, we can draw a triangle. It moves a distance:

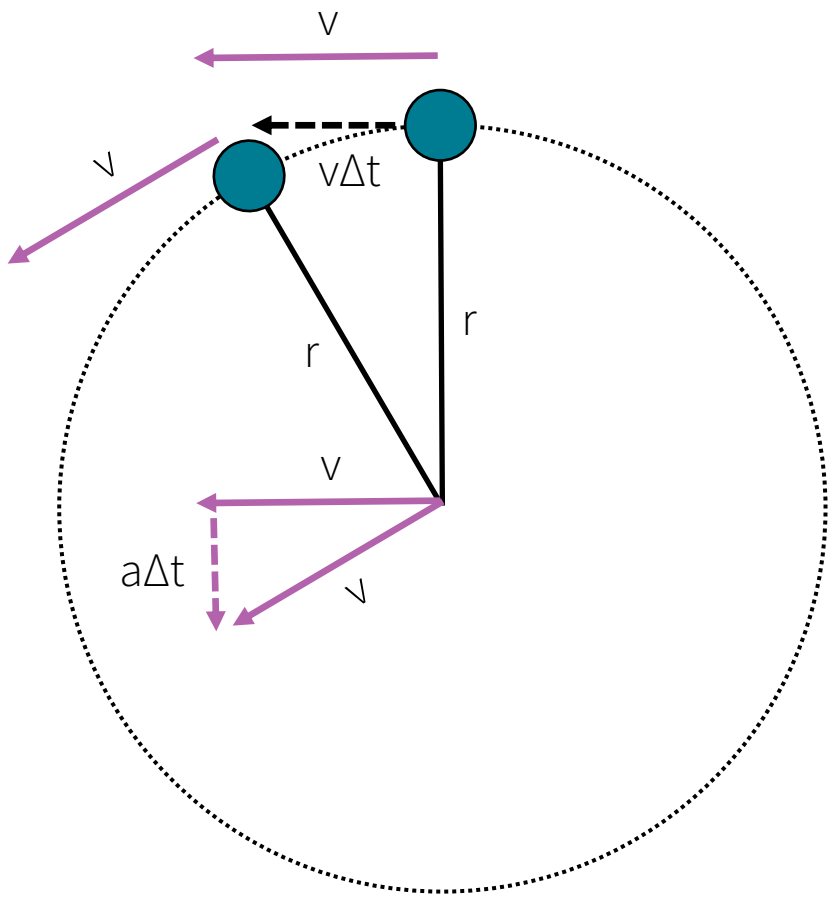
$$d = v\Delta t$$

- We can draw a second triangle of the velocities. The angle between them is the same, so they are *similar triangles*. This means that

$$\frac{a\Delta t}{v} = \frac{v\Delta t}{r}$$ TMI

- Therefore, the acceleration, towards the center of the circle

$$a = \frac{v^2}{r}$$ MaT



MaT

Motion in a Circle

- The angular velocity is the angle the ball travels round the circle per time t:

$$\omega = \frac{\theta}{t}$$

- The distance travelled around a little bit of the circle, $d = \theta r$, so the linear velocity (the speed the ball is travelling at):

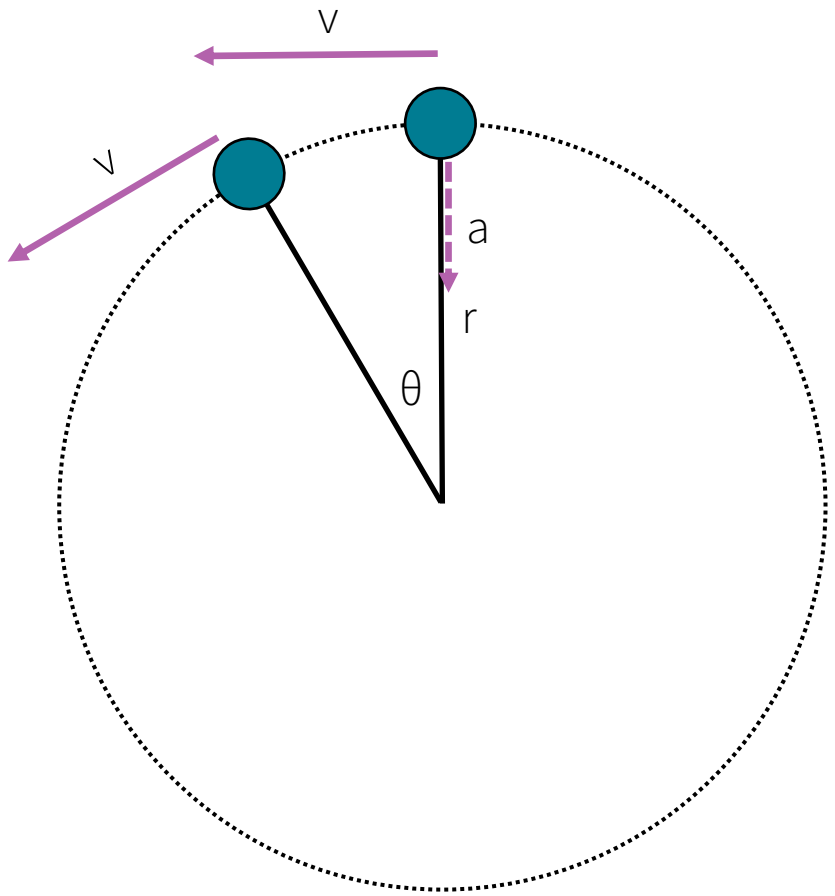
$$v = \omega r$$

- The total distance the ball has to travel to complete one circuit is the circumference, $D = 2\pi r$, so the period (the time taken to complete one circuit)

$$P = \frac{2\pi}{\omega} \text{ or } P = \frac{2\pi r}{v}$$

- The ball is always accelerating towards the center of the circle

$$a = \frac{v^2}{r} \text{ or } a = \omega^2 r$$



QaD

Hubble Space Telescope

Hubble orbits the Earth at an altitude:

$$h = 550\text{km}$$

The radius of the Earth is ~6300km, so the radius of Hubble's orbit is

$$r = 6300 + 550 = 6850\ \text{km}$$

It completes one orbit in a time period:

$$P = 95\ \text{min} = 5{,}700\ \text{s}$$

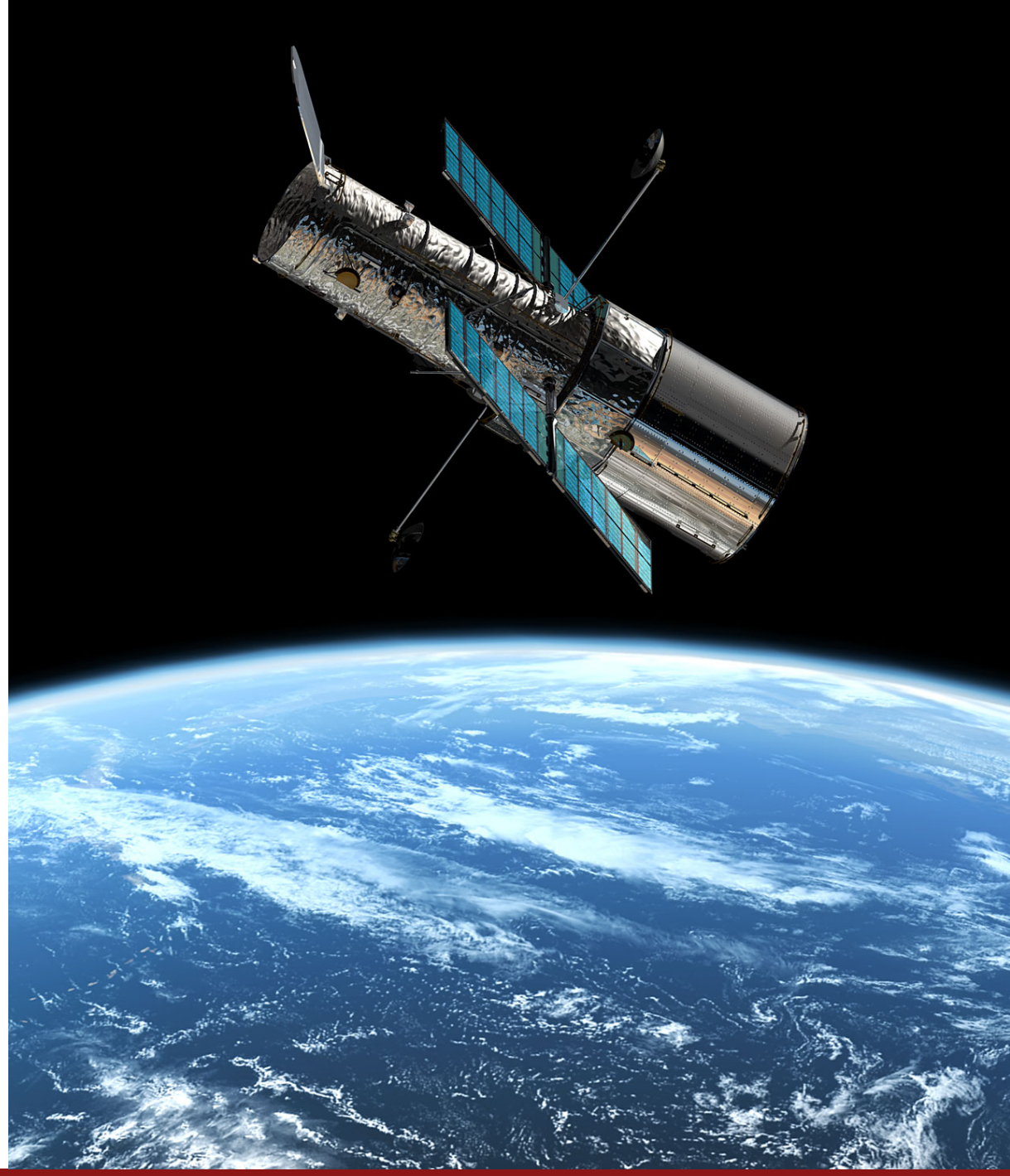
Therefore, its speed:

$$v = \frac{2\pi r}{P} \approx 8\ \text{km s}^{-1}$$

And acceleration:

$$a = \frac{v^2}{r} \approx 9\ \text{m s}^{-2} \approx g$$

Close to the Earth, acceleration due to gravity is approx. constant



QaD

The Moon

Distance from Earth:

r = 400,000km

Period

P = 27 days

Therefore, its speed:

$$v = \frac{2\pi r}{P} \approx 1\ \mathrm{km\ s^{-1}}$$

And acceleration:

$$a = \frac{v^2}{r} \approx \frac{1}{400}\ \mathrm{m\ s^{-2}} \approx \frac{g}{4000}$$

QaD

The Earth

Distance from Earth to Sun:

r ~ 150,000,000km = 1 AU (“Astronomical Unit”)

Period

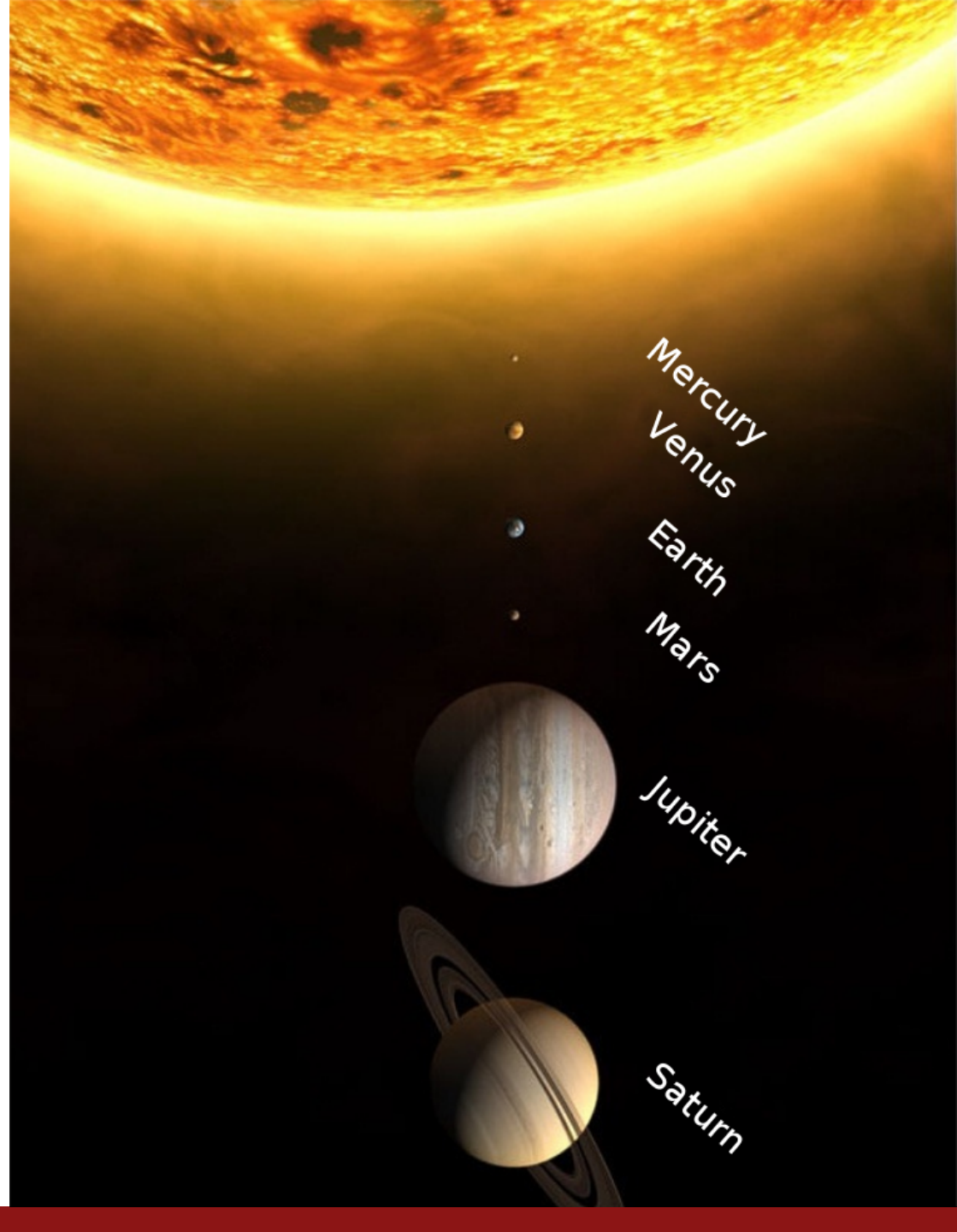
P = 1 year ~ 30,000,000 s

Therefore, its speed:

$$v = \frac{2\pi r}{P} \approx 30\ \mathrm{km\ s^{-1}}$$

And acceleration:

$$a = \frac{v^2}{r} \approx 10\ \mathrm{mm\ s^{-2}} \approx \frac{g}{1000}$$



Exponential Notation

MaT

For writing down big or small numbers…

$100 = 10^2$ | $1/100 = 0.01 = 10^{-2}$

$1000 = 10^3$ | $1/1000 = 0.001 = 10^{-3}$

$1000000 = 10^6$ | $1/1000000 = 0.000001 = 10^{-6}$

Scientific notation…

$300 = 3 \times 10^2$ | $0.05 = 5 \times 10^{-2}$

$4{,}500 = 4.5 \times 10^3$ | $0.00101 = 1.01^{-3}$

$2{,}010{,}000 = 2.01 \times 10^6$ | $0.000000055 = 5.5^{-8}$

Multiplication and division made easy…

$10^6 \times 10^9 = 10^{6+9} = 10^{15}$ | $10^6 / 10^9 = 106^{-9} = 10^{-3}$

$3x10^6 \times 5x10^9 = (3x5) \times 10^{6+9} = 1.5 \times 10^{16}$ | $6x10^6 / 2x10^4 = (6/2) \times 10^{6-4} = 3 \times 10^2$

SI notation

1km (1 kilometer) = 10^3 m | 1cm (1 kilometer) = 10^{-2} m

1Mm (1 megameter) = 10^6 m | 1mm (1 milimeter) = 10^{-3} m

1Gm (1 gigameter) = 10^9 m | 1µm (1 micrometer) = 10^{-6} m

Some numbers to get your head around...!

- Approx. 10^{19} grains of sand on the Earth
- 10^{11} galaxies in the (visible) Universe (at least!)
- 10^{22} stars in the Universe

QaD

The Stars in the Galaxy

Stars in the outer arms travel at:

$$v \sim 300 \text{ km s}^{-1}$$

Distance from center to outer arms:

$$r = 3 \times 10^{20} \text{ m}$$

Therefore, the period of time for the Sun to complete one orbit:

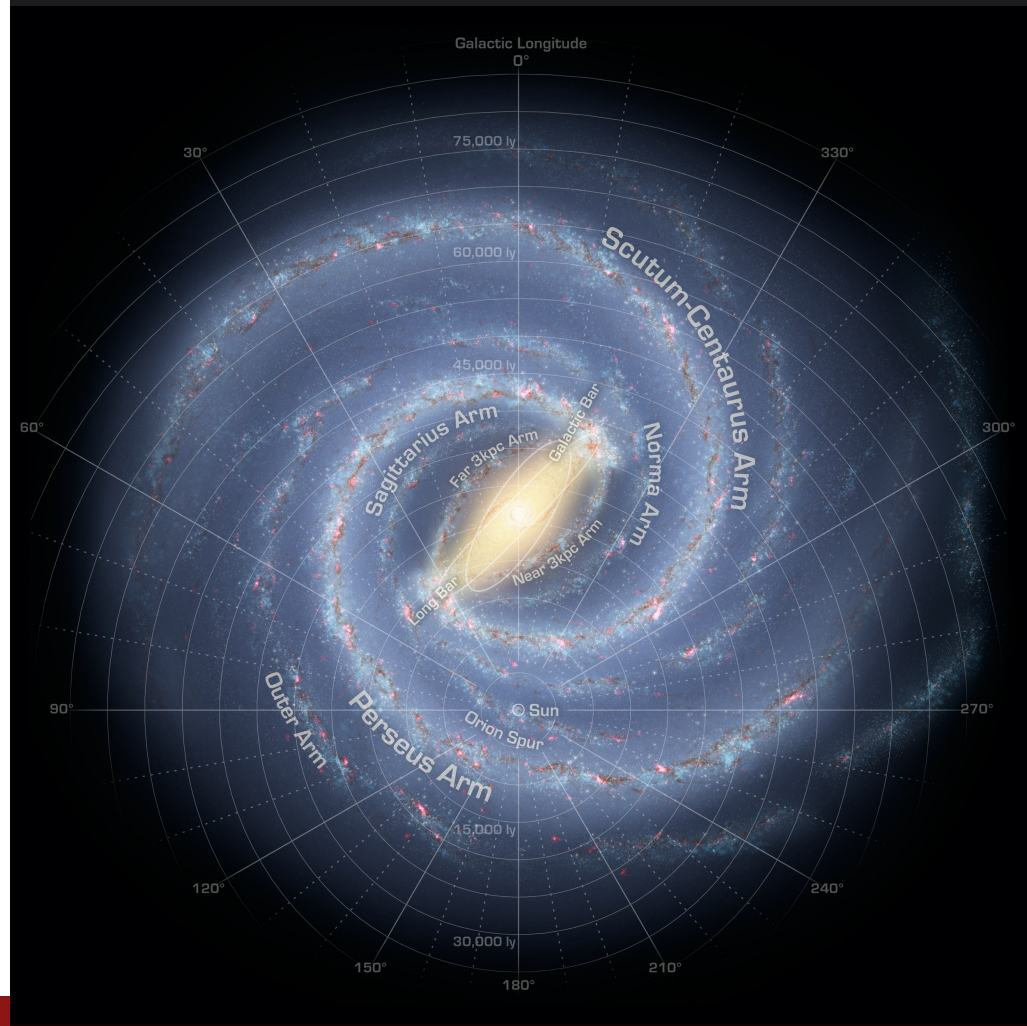
$$P = \frac{2\pi r}{v} \approx 2 \times 10^{8} \text{ yr}$$

And acceleration:

$$a = \frac{v^2}{r} \approx 3 \times 10^{-10} \text{ m s}^{-2} \approx 10^{-11} g$$

We are in the Milky Way, a spiral galaxy. Our Sun is one of about 100,000,000,000 stars

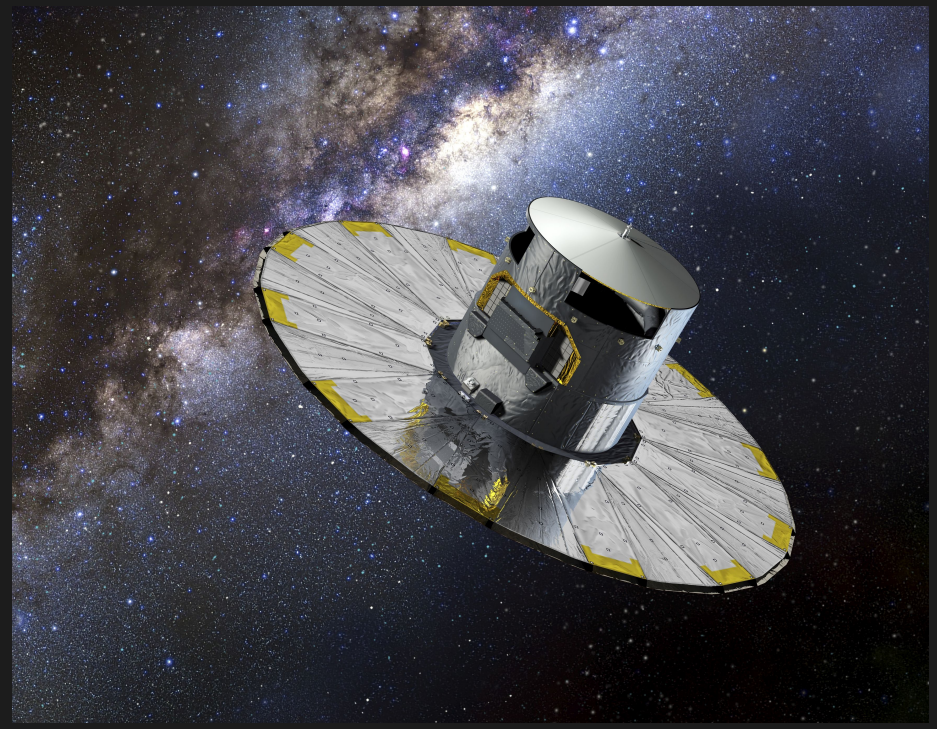
The stars travel in orbit around the center of the galaxy



The Dance of the Stars

ESA’s Gaia satellite is accurately mapping the positions and measuring the (extremely slight) motion

Based on these measurements, we can predict where the stars will be in the sky millions of years from today



QaD

- Radii, periods, speeds and accelerations of orbits

MaT

- Exponential notation
- Scaling relations
- Motion in a circle

WILtY

- Mathematics of geometry

Bigl

- Space and time
- Displacement, velocity, acceleration
- Gravitational acceleration
- Orbits
- Testing theories with experiment